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(54) **System for controlling production from a gas-lifted oil well**

(57) A system for controlling production from a gas-lifted oil well comprises a dynamically controlled choke (1) for adjusting the flow of crude oil from a production tubing (2) of the well. The system is capable of maximizing and stabilizing the crude oil production in an accurate manner and without requiring downhole equipment.

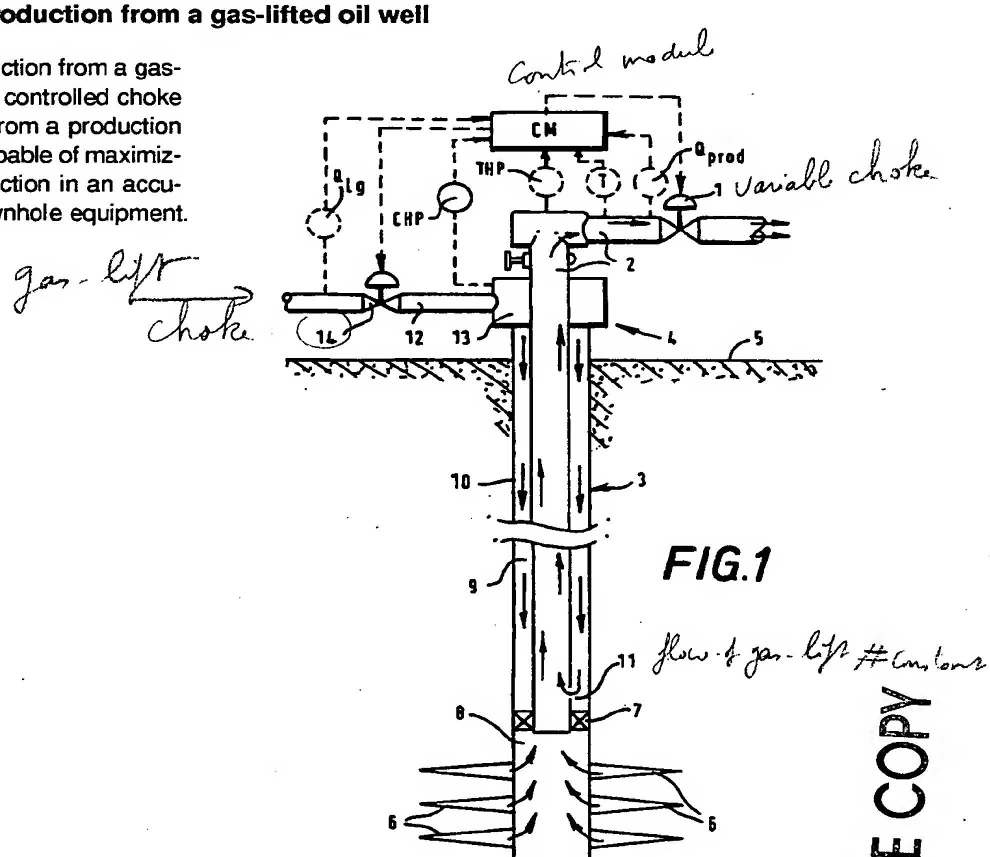

FIG.1

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Description

The invention relates to a system for controlling production of crude oil through a production tubing which extends into a gas-lifted oil well whereby lift-gas is injected at a downhole location.

In such gas-lifted oil wells the pressure in the production tubing may fluctuate which may lead to an irregular in-flow of lift-gas that is injected into the production tubing. Such irregular injection of lift-gas may eventually cut off production of oil all together. Consequently such unstable gas-lifted wells tend to see-saw between oil-producing and non-oil-producing states whereby slugs of crude oil and lift-gas are produced.

It is common practice to adjust the flow of lift-gas that is injected into the well by means of a choke to such a level that the production of crude oil is maximized and stabilized.

The article "Wellhead monitors automate Lake Maracaibo gas-lift" published by J C Adjunta and A Majek on pages 64-67 of the Oil and Gas Journal of 28 November 1994 discloses that an automatic choke may be used which varies the flow of lift-gas such that it stays close to a calculated optimum.

In the system known from this prior art reference the choke is located at the earth surface near the wellhead of the gas-lifted well. A problem encountered with the known system is that the gas injection conduit, which is usually formed by the annular space between the production tubing and the well casing, may have a length of several kilometres and may have such a large volume that it is not possible to accurately control the amount of lift-gas which is injected downhole into the production tubing by adjusting the flow of lift-gas that enters the lift-gas injection conduit via the variable choke at the wellhead.

It is also known, for example from International patent application PCT/EP 95/00623, to adjust the flow of lift-gas which is injected into the oil production tubing by means of a surface controlled variable downhole orifice via which the lift-gas is injected into the production tubing.

Such a variable downhole orifice enables an accurate control of the amount of lift-gas into the well such that always a steady flow of lift-gas is injected and a stable and optimum gas-lift is created.

However, the installation, operation and maintenance of such a variable downhole orifice is expensive. In particular if the well is equipped with a dual completion, which may consist of two concentric production tubings that extend to various depths in the well, and gas is injected via the surrounding annulus and orifices near the bottom of each of these tubings, then the installation of a set of two downhole valves in the well may not be economical.

It is an object of the present invention to provide a system which is able to accurately control the injection of gas into a gas-lifted oil production well such that the crude oil production is maximized and stabilized and which does not require the use of downhole control equipment.

The system according to the invention thereto comprises a variable choke for adjusting the flow of crude oil through said production tubing; and a control module for dynamically controlling the opening of the choke.

Preferably, the control module is set to dynamically control the opening of the choke in response to variations in the fluid pressure within the lift-gas conduit.

In such case the control module usually varies the opening of the choke such that a constant flow of lift-gas is injected into the production tubing and that no slug flow occurs.

An accurate control can be obtained if the control module comprises a PID controller which is set to dynamically control the opening of the choke in such a manner that the fluid pressure within said lift-gas injection conduit is minimized and stabilized and which uses the pressure measured by a pressure gauge in the lift-gas injection conduit as input signal and the choke position as output signal.

It will be understood that a PID controller is a controller which gives an output signal which is proportional to the input signal, but which also integrates and differentiates the input signal to adjust the characteristics of the output signal.

The control module may further comprise a master controller which incorporates a fuzzy logic algorithm to generate for the PID controller a setpoint for the pressure in the lift-gas injection conduit.

The concept of a fuzzy logic control and of a fuzzy controlled PID controller is known per se and described for example in chapter 3 of the Handbook of Intelligent control: Neural, Fuzzy and Adaptive Approaches written by A White and D A Sofge and issued by van Nostrand Reinhold, New York, 1992.

Conveniently the variable choke and control module are located at the earth surface at a location near the wellhead of the gas-lifted oil production well.

The location of the choke and control module at the earth surface allows installation and maintenance thereof outside the well and without interruption of oil production operations which saves significant cost and effort. This is particularly relevant if the well comprises a plurality of crude oil production tubings and lift-gas is injected at various downhole locations into the various production tubings via a common gas injection conduit which is at least partly formed by an annular space between the production tubings and a well casing, and wherein each production tubing is equipped with a production control system according to the invention.

These and other features, objects and advantages of the system according to the invention will become apparent from the accompanying claims, abstract and drawings.

In the drawings:

Fig. 1 shows a schematic longitudinal sectional view of a crude oil production well in which the

crude oil production is controlled by a system according to the invention;

Fig. 2 shows a flowscheme of the control logic for the control module CM of the control system shown in Fig. 1;

Fig. 3 shows a flowscheme which further explains the operation of the control logic for the control module CM of the control system shown in Fig. 1; and

Fig. 4 is a graph which shows the results of an experiment which indicates that the control system according to the invention is able to optimize and stabilize production from a gas-lifted well.

Referring now to Fig.1 there is shown a gas-lifted crude oil production well comprising a variable choke 1 and a control module CM according to the invention.

The choke 1 is mounted in a production tubing 2 which extends from near the bottom of an oil production well 3 through the wellhead 4 towards processing facilities (not shown) at the earth surface 5.

Oil is produced via perforations 6 that have been shot into an oil bearing formation. A packer 7 is mounted near the lower end of the production tubing 2 which provides a fluid barrier between the inflow zone 8 at the bottom of the well and the annular space 9 that is formed between the outer surface of the production tubing 2 and the inner surface of a well casing 10.

To stimulate the production of crude oil via the production tubing 2 lift-gas is injected via the annulus 9 and a downhole orifice 11 into the production tubing 2.

The lift-gas is fed into the annulus via a gas injection conduit 12 and an annular chamber 13 at the wellhead 4. The gas injection conduit 12 is equipped with a choke 14 which serves to adjust the flow of lift-gas. However, the considerable volume and length of the annular space 9 result in a significant delay between the moment at which the position of the choke 14 is varied and the moment that this results in a variation of the flow of gas that passes through the downhole orifice 11.

The variable choke 1 and the control module CM according to the invention serve to avoid that swift variations in the fluid pressure in the production tubing 2 would result in an unstable lift-gas injection regime whereby the lift-gas is injected in slugs via the downhole orifice 11 into the production tubing 2 and the well would start to produce irregular slugs of crude oil and lift-gas.

The control module CM according to the invention is continuously or intermittently fed with data concerning the casing head pressure CHP measured by a pressure gauge at the top of the annular space 9 and the tubing head pressure THP measured by a pressure gauge at the top of the tubing 2. Also data are fed to the control module CM concerning the temperature T of the produced fluid mixture and the flow of lift gas Q_{lg} and of the produced fluid mixture Q_{prod} measured by flowmeters that are mounted in the lift-gas injection conduit 12 and the production tubing 2, respectively. In the embodiment shown the control module CM does not only control the opening of the production choke 1, but also the opening of the lift-gas injection choke 14.

The principal operation of the control module CM is that it adjusts the opening of the production choke 1 such that the flow of lift-gas through the downhole orifice 11 remains approximately constant. This is achieved by maintaining a constant differential pressure across the downhole orifice. The pressure downstream of the orifice can be influenced by varying the backpressure at the wellhead, i.e. the tubing head pressure THP. In this way the backpressure exerted by the tubing head pressure THP on the produced fluid mixture is varied such that the backpressure increases in response to a decrease in the measured casing head pressure CHP and vice versa. This variation of the tubing head pressure THP is an adequate measure to accomplish a substantially constant rate of injection of lift-gas at the downhole orifice 11.

The control module CM aims to minimize the casing head pressure CHP by variation of the opening of the production choke 1.

Without constraints, however, further and further opening of the production choke 1 would lead to instability. Therefore, the control module CM is set to obey another rule which dictates that the lower the lift-gas injection rate Q_{lg} is the wider the control margin Cm(t) on the production choke 1 needs to be. Setting this control margin Cm(t) requires some empirical judgement which is incorporated into a fuzzy control unit FCU which is described in more detail with reference to Fig. 2 and Fig. 3.

Referring now to Fig. 2 there is shown a block-scheme which shows the operation of the control module CM.

The heart of the control module CM is formed by a conventional PID controller, in the block-scheme referred to as PID, which adjusts the position Cp(t) of the production choke 1 in response to variations of the measured casing head pressure CHP.

The flowscheme shows that the casing head pressure CHP is dependant of the tubing head pressure THP, the pressure P_{res} of the fluid in the pores of the reservoir formation RES, and also on the lift-gas injection rate Q_{lg} via the lift-gas choke 14 and the downhole orifice 11.

The fuzzy control unit FCU provides a casing head pressure setpoint CHP sp(t) for the PID controller and also adjusts the position of the lift-gas injection choke 14 on the basis of empirical data, represented by arrow 20, which identify classes of suitable positions of the chokes 1 and 11 for various production rates.

Accordingly the fuzzy control unit FCU acts as a master controller for the PID controller.

The interaction between the fuzzy control unit FCU and the PID controller will be described in more detail with reference to the flowscheme shown in Fig. 3.

The flowscheme will be described from top to bottom and the actions of the fuzzy control unit FCU and PID controller PID are contained within phantom lines.

The first box at the top indicates that a control cycle starts with a measurement at a certain moment in time (t) of the lift-gas injection rate $Q_{lg}(t)$, the casing head pressure CHP(t) and the actual position Cp(t) of the production choke 1.

The next box indicates that on the basis of the measured gas flow rate $Q_{lg}(t)$ the fuzzy control unit calculates the choke margin Cm(t).

Subsequently the fuzzy control unit FCU verifies whether the actual choke position Cp(t) is below the choke margin Cm(t).

If this is indeed the case the fuzzy control unit FCU will decrease the setpoint for the casing head pressure CHPsp(t) for the PID controller, whereas if this is not the case said setpoint CHPsp(t) will be increased.

The PID controller subsequently verifies whether the measured casing head pressure CHP is lower than the setpoint CHPsp(t) supplied by the fuzzy control unit FCU.

If this is indeed the case the PID controller will decrease the choke opening Cp(t), whereas if this is not the case the PID controller will increase the choke opening.

The measurement and control cycle is then repeated after a selected interval of time and the same steps of the procedure set out in the flowscheme are taken again.

The performance of the control module according to the invention was tested in a miniaturized well in which water was produced via an 18 metres high riser pipe and in which air was injected as lift-gas via an annulus surrounding the pipe to enhance the flow of water through the riser pipe.

During the experiment the lift-gas injection rate Q_{lg} was 15 m^3 per day and the productivity index PI, simulated with a variable restriction, was 10 m^3 per day per bar.

The graph shown in Fig. 4 shows the response of the casing head pressure CHP and fluid production rate Q_{prod} to various settings of the production choke at the top of the riser pipe. The horizontal axis of the graph represents elapsed time, in seconds. The vertical axis contains a scale of 0-100 units which represent both the opening Cp of the production choke (in %), the measured casing head pressure CHP times a factor 50 (in bar) and the fluid production rate Q_{prod} times a factor 10 (in m^3 per day).

At the start of the experiment, between t = 0 and 240 s, the production choke position Cp was fixed at 60% open. Without dynamic control, a fixed choke setting of 60% was required to achieve stable production.

The graph shows that at this choke setting the production rate Q_{prod} was stable and averaged 1.9 m^3/day.

At t = 240 s the control module according to the invention was switched on and accomplished an optimum choke setting Cp = 91% open at t = 420 s.

At this point the average production Q_{prod} equalled 3 m^3 per day, which represents a production increase of 55%.

At t = 660 s the control module according to the invention was switched off and the choke setting remained fixed at 91% open. The graph shows that the production became unstable and the production rate Q_{prod} dropped to about 1.4 m^3 per day.

At t = 960 s the control module according to the invention was switched on again. It detected that there was no gas injection downhole because the casing head pressure CHP did rise and the control module fully opened the production choke. When downhole lift-gas injection started again and the casing head pressure CHP thus dropped the control module partly closed the choke and opened it again to reach stable and optimum production again at a rate of about 3 m^3 per day.

It will be understood that the continuous or intermittent variation of the production choke opening consumes a significant amount of power.

If the well is located at a remote location and electrical power is not readily available, power for actuating the production choke could be generated by a positive displacement motor or other rotary power generator which utilizes the elevated pressure of the lift-gas within the lift-gas injection conduit as a power source. Preferably the inlet of the motor or generator is connected to the lift-gas conduit and the outlet thereof to the oil production tubing.

The control system according to the invention is also suitable for use on a well which comprises a plurality of crude oil production tubings which produce crude oil from various locations in a reservoir. Such a well with multiple completions may produce crude oil either from various inflow regions along a single wellbore or from various inflow regions along different downhole branches. In such case various production tubings may be arranged concentrically within the upper part of the well and lift-gas may be injected at different depths into the production tubings via the annular space formed between the outermost tubing and the well casing. If in such case each production tubing is provided with a control system according to the invention which adjusts the opening of a production choke near the top of the production tubing in question in the manner described with reference to the drawings then a stable gas injection and an optimum crude oil production is accomplished in each of the production tubings.

Claims

1. A system for controlling production of crude oil through a production tubing which extends into a gas-lifted oil production well and into which lift-gas is injected at a downhole location, the system comprising:

   - a variable choke for adjusting the flow of crude oil through said production tubing; and
   - a control module for dynamically controlling the opening of the choke.

2. The system of claim 1, wherein the control module is set to dynamically control the opening of the choke in response to variations of the fluid pressure within the lift-gas conduit.

3. The system of claim 2, wherein the control module comprises a PID controller which is set to dynamically control the opening of the choke in such a manner that the fluid pressure within said lift-gas injection conduit is minimized and stabilized and which uses the pressure measured by a pressure gauge in the lift-gas injection conduit as input signal and the choke position as output signal.

4. The system of claim 3, wherein the control module further comprises a master controller which incorporates a fuzzy logic algorithm to generate for the PID controller a setpoint for the pressure in the lift-gas injection conduit.

5. The system of any preceding claim, wherein the variable choke and control module are located at the earth surface at a location near the wellhead of the gas-lifted oil production well.

6. The system of any preceding claim, wherein the well comprises a plurality of crude oil production tubings and lift-gas is injected at various downhole locations into the various production tubings via a common gas injection conduit which is at least partly formed by an annular space between the production tubings and a well casing, and wherein each production tubing is equipped with a production control system according to any preceding claim.

7. The system of any preceding claim, wherein the variable choke is equipped with power means which utilizes the elevated fluid pressure of the lift-gas within the lift-gas injection conduit as a power source.

8. The system of claim 7, wherein the power means consist of a positive displacement motor of which an inlet is connected to the lift-gas injection conduit and an outlet is connected to the production tubing or one of the production tubings.

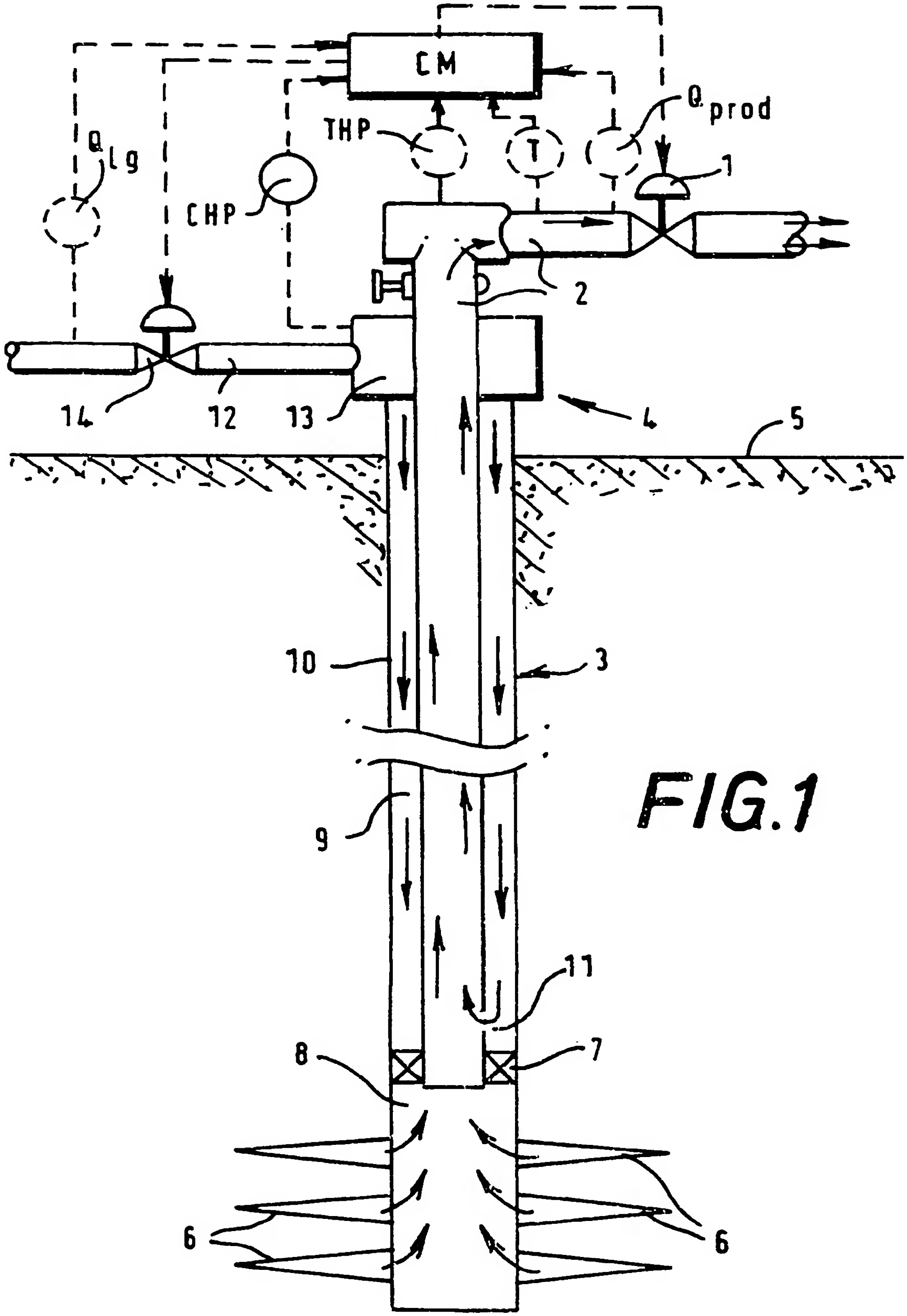


FIG.1

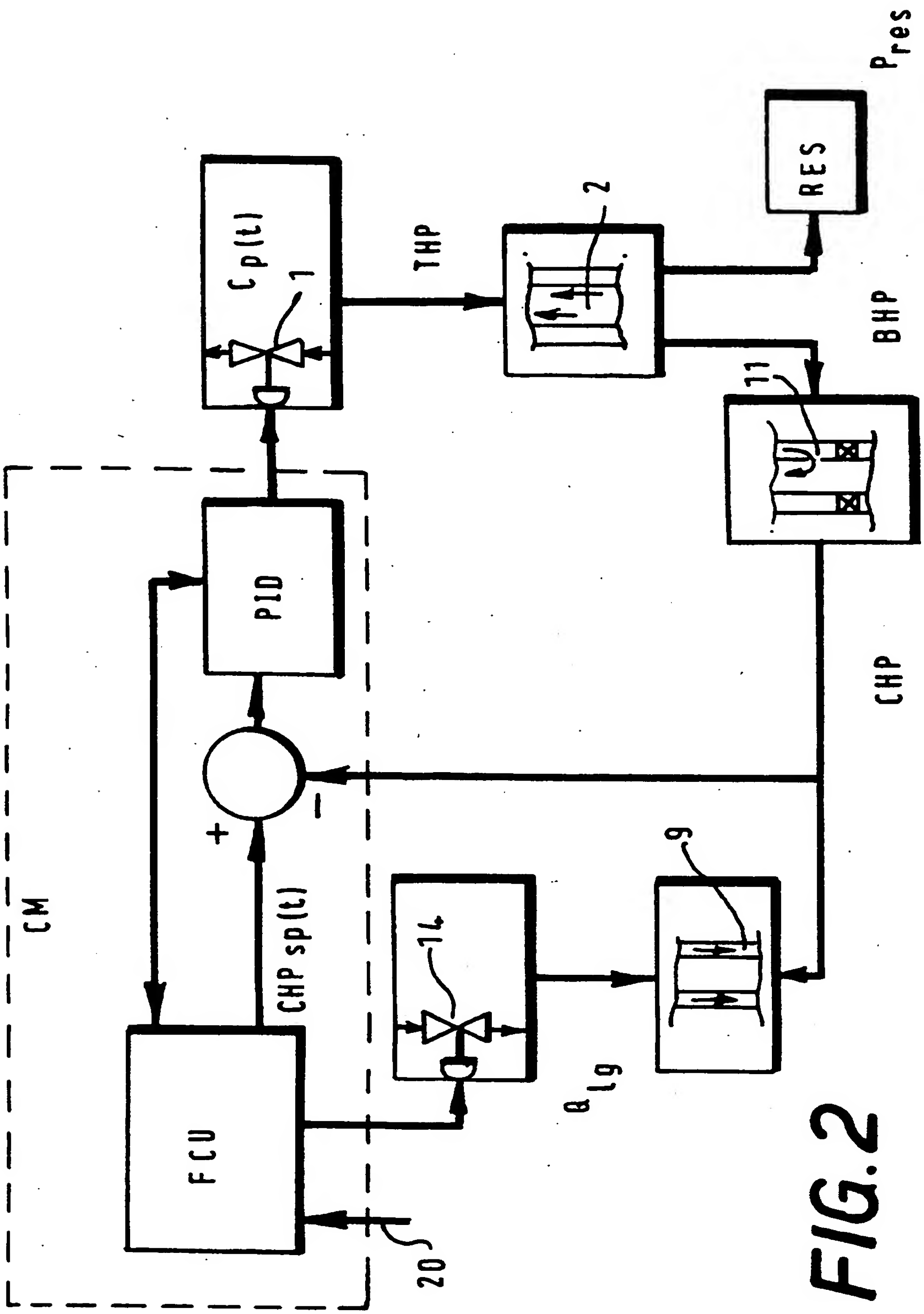
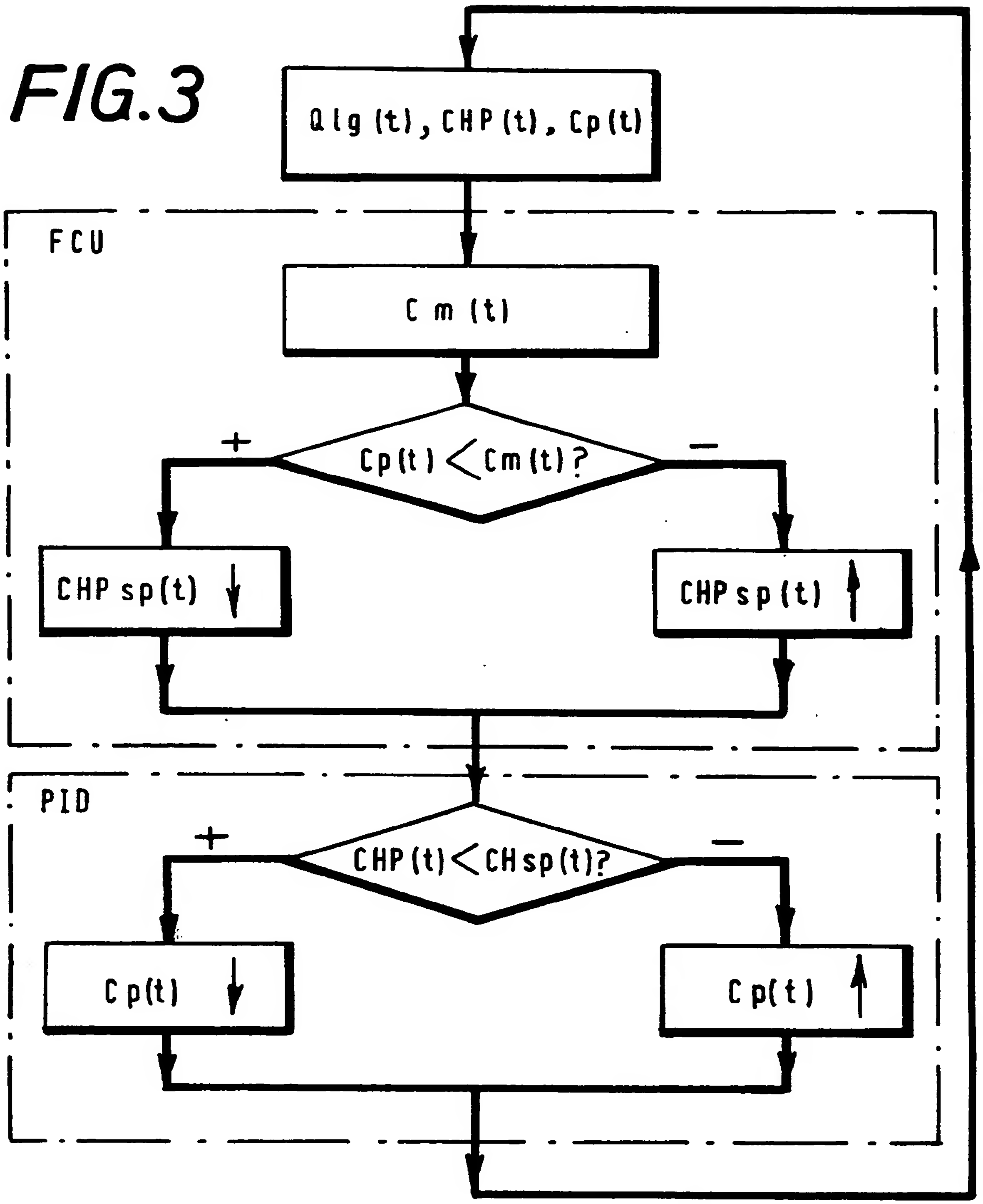


FIG.2

FIG.3


Qlg (t), CHP (t), Cp (t)
FCU
C m (t)
Cp(t) < Cm(t)?
+
−
CHP sp(t)
CHP sp (t)
PID
CHP (t) < CH sp (t)?
+
−
C p(t)
C p(t)

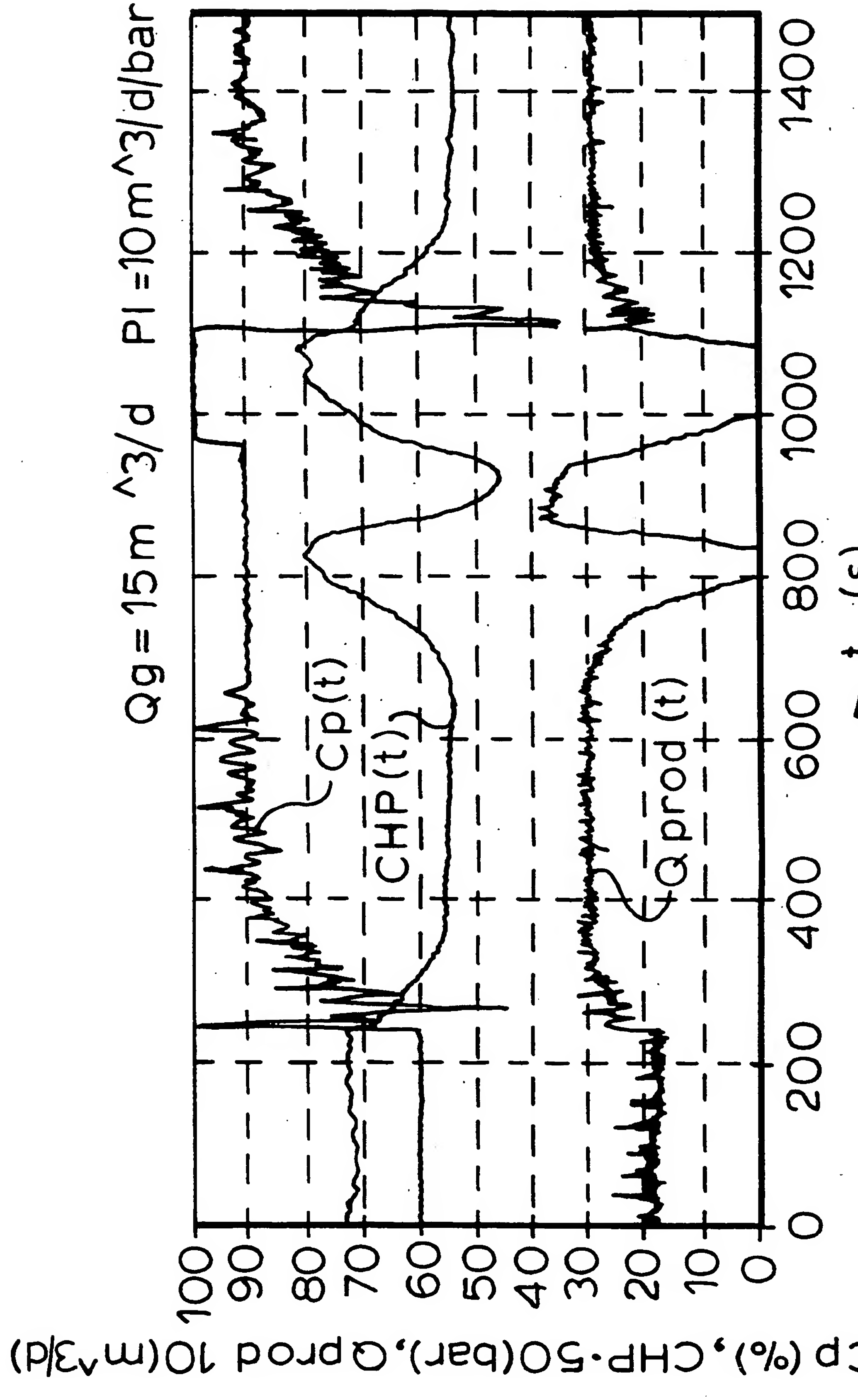

Qg = 15 m ^3/d   PI = 10 m^3/d/bar
Cp(t)
CHP(t)
Q prod (t)
t (s)
Cp (%), CHP-50(bar), Q prod 10(m^3/d)
0
200
400
600
800
1000
1200
1400
0
10
20
30
40
50
60
70
80
90
100

FIG.4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 20 2038

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GB-A-2 252 797 (SOCIETE NATIONALE ELF AQUITAINE) * page 4, line 10 - page 5, line 2 * * page 7, line 3 - line 10 *	1-3,5	E21B43/12
Y		6	
X	WO-A-88 00277 (B.W.N. VORTOIL PTY. LTD.) * claim 4 *	1,5	
Y	US-A-5 172 717 (BOYLE ET AL.) * column 27, line 66 - column 29, line 28; figure 9 *	6	
A	US-A-2 298 834 (MOORE) * page 1, right column, line 45 - page 2, left column, line 44 *	6	
D,A	OIL & GAS JOURNAL, 28 November 1994 pages 64-67, ADJUNTA ET AL. 'Wellhead monitors automate Lake Maracaibo gas lift' * second column of paragraph "Technology" on page 65 *	7,8	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
E21B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 January 1996	Rampelmann, K

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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